

# PRELIMINARY MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION FROM NEUTRINO-NUCLEON DEEPLY INELASTIC SCATTERING AT NUTEV

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Preliminary results for the neutrino-nucleon differential cross section from the NuTeV experiment are presented. The extraction of the differential cross section from NuTeV is discussed and the structure functions  $F_2$  and  $\Delta x F_3$  are presented. Comparisons are made with CCFR results.

## Introduction

Neutrino-nucleon experiments offer a rich source of information about the quark structure of the proton.<sup>1</sup> Neutrino-nucleon deeply inelastic scattering (DIS) is arguably the most direct measurement of the proton structure functions.

The NuTeV experiment observed  $6 \times 10^5$  neutrino ( $\nu_\mu$ ) and  $3 \times 10^5$  anti-neutrino ( $\bar{\nu}_\mu$ ) charged-current interactions in an iron/scintillator calorimeter.<sup>2</sup> The NuTeV beam was generated from 800 GeV protons on a beryllium oxide target; secondary pions and kaons were sign-selected using

a quadrupole magnet train. NuTeV included a precision calibration beam designed to reduce the uncertainty of the absolute muon and hadron energy scale.

## Extracting the Differential Cross Sections

The differential cross section is determined from the differential number of events  $\frac{d^2 N}{dx dy}$  and a flux factor  $L(E)$  at a given neutrino energy,

$$\frac{d^2 \sigma^{\nu(\bar{\nu})}}{dx dy} = \frac{1}{L(E)} \frac{d^2 N^{\nu(\bar{\nu})}}{dx dy}. \quad (1)$$

In Eq. 1, the kinematic variables  $x$  and  $y$  represent the Bjorken scaling variable (the fractional momentum of the struck quark), and the inelasticity. NuTeV reconstructs these kinematic variables and the energy of the neutrino. The NuTeV kinematic range extends from about  $10^{-3}$  to 0.95 in  $x$  and from 0.05 to 0.95 in  $y$ ; the energy reach is from 30 GeV to about 400 GeV.

The differential number of events is determined from a sample of events which pass charged current quality cuts, which demand event containment, a minimum hadronic energy ( $\nu$ ) of 10 GeV, a momentum analyzed muon, and a minimum  $Q^2$  cut. The selected events are binned in  $x$ ,  $y$ , and  $E$ ; are corrected for detector effects; and are acceptance corrected using a fast detector simulation. The binning is chosen to approximately reflect the detector resolution.

A nearly orthogonal sample of events is selected to determine the flux. These events must pass a maximum hadronic energy cut of 20 GeV. The flux is solely a function of the neutrino energy and is determined by expanding the flux differential cross section in terms of  $\frac{\nu}{E}$ . To first order, up to corrections of order  $\frac{\nu}{E}$ , the flux is proportional to the number of events in this sample. The  $\frac{\nu}{E}$  corrections are obtained by fitting for the coefficients of  $\frac{\nu}{E}$  and relating the coefficients to physical quantities. This procedure determines the relative flux as a function of energy. The flux is normalized to the world total neutrino cross section by using a third sample which includes both the flux and the charge current sample.

The fast detector simulation, which takes into account acceptance and resolution effects, includes an empirically determined set of parton distribution functions with QCD evolution.<sup>3</sup> The parton distribution functions are determined by fitting the extracted differential cross section. The fitted parton distributions are used to determine acceptance corrections for both the DIS and flux sample. The procedure is then iterated. As a typical example, the differential cross section at  $E = 95$  GeV is shown in Fig. 1. NuTeV is found to be in good agreement with CCFR.<sup>4</sup>

In terms of  $\epsilon$  (the polarization of the virtual  $W$ ) the sum of the anti-neutrino and neutrino differential cross sections can be written

$$F(\epsilon) = \frac{\pi(1-\epsilon)}{y^2 G_F^2 M_p E_\nu} \left( \frac{d^2 \sigma^\nu}{dx dy} + \frac{d^2 \sigma^{\bar{\nu}}}{dx dy} \right) = 2xF_1 \left[ 1 + \epsilon R(x, Q^2) \right] + g(y) \Delta x F_3. \quad (2)$$

The rightmost equation allows the function  $F(\epsilon)$  to be related to the underlying physical quantities. The structure functions  $2xF_1$  and  $\Delta x F_3 = x(F_3^\nu - F_3^{\bar{\nu}})$  are functions of  $x$  and  $Q^2$  only. The  $y$ -dependence of the differential cross section is contained in  $\epsilon = \frac{2(1-y) - M_p xy/E}{1 + (1-y)^2 + M_p xy/E}$  and  $g(y) = \frac{y(1-y/2)}{1 + (1-y)^2}$ . The coefficients from the fit of  $F(\epsilon)$  to the terms  $(1 + \epsilon R(x, Q^2))$  and  $g(y)$  represent  $2xF_1$  and  $\Delta x F_3$ , respectively. The structure function  $F_2$  is given by  $F_2 = 2xF_1(1 + R(x, Q^2))$ .

## Results

While the differential cross section offers the most fundamental picture of neutrino (anti-neutrino) DIS, the structure functions illuminate the underlying physical quantities. Unfortunately, knowl-

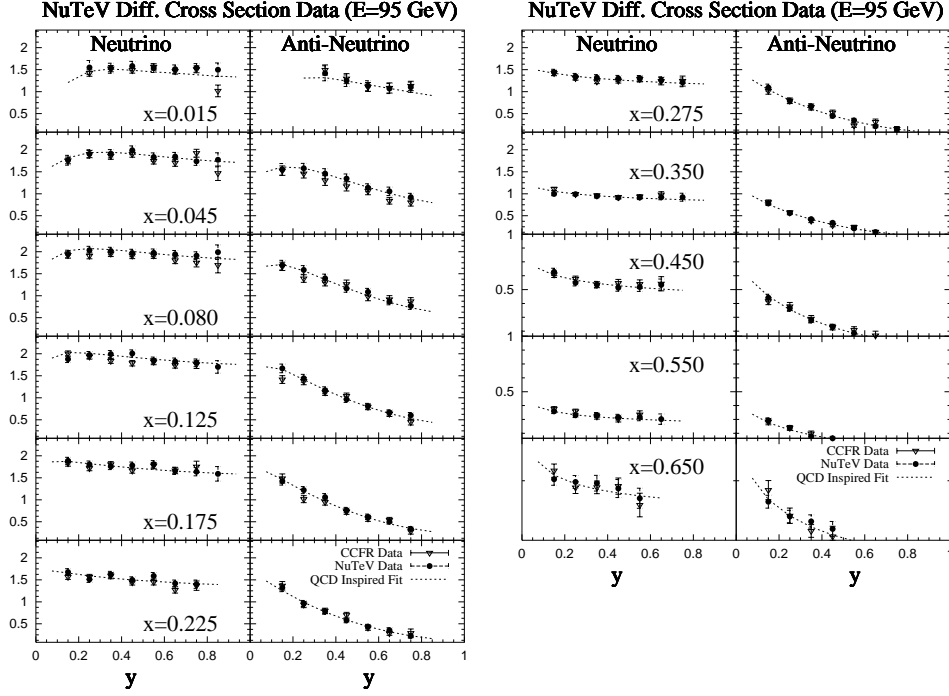


Figure 1: Neutrino and anti-neutrino (side by side) differential cross section from NuTeV (closed circles) and CCFR (open triangles) as a function of  $y$  with the QCD inspired fit to the NuTeV data. Only statistical errors are shown. The differential cross section should be scaled by  $G_F^2 M/E_\nu$  to obtain the proper units. The dashed line is the NuTeV differential cross section calculation using empirically determined parton distribution functions.

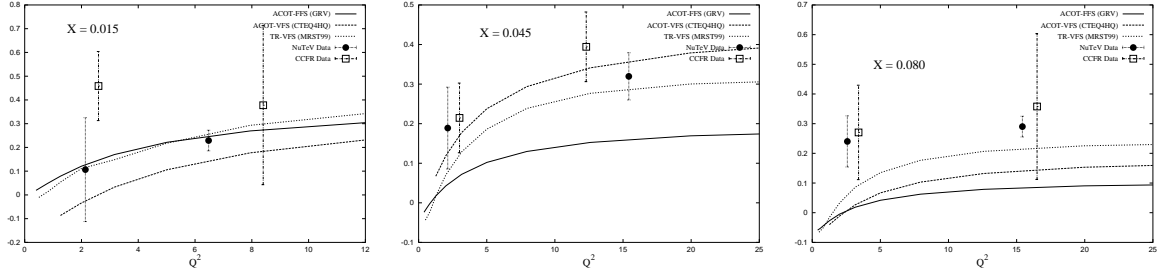


Figure 2: Fit components of  $F(\epsilon)$  and model independent extraction of  $\Delta x F_3$  for CCFR and NuTeV at  $x = 0.015, 0.045$ , and  $0.080$  and NLO models for  $\Delta x F_3$  as a function of  $Q^2$ . NuTeV data are shown as closed circles with statistical errors only; CCFR data, open boxes with statistical and systematic errors.

edge of both  $R(x, Q^2)$  and  $\Delta x F_3$  is limited in the low- $x$ , low- $Q^2$  region.<sup>4,5</sup>  $F_2$ ,  $R$ , and  $\Delta x F_3$  cannot be simultaneously fit due to inadequate statistics and strong correlations among the parameters.

A model or extrapolation for either  $R(x, Q^2)$  or  $\Delta x F_3$  must be provided as input for any extraction. The results shown in Fig. 2 use the world parameterization of  $R(x, Q^2)$ <sup>6</sup> and are shown with models of parton distributions functions from fixed and variable flavor schemes: Shown are ACOT fixed flavor scheme (ACOT-FFS) using GRV parton distributions; ACOT variable flavor scheme using CTEQ4HQ (ACOT-VFS); and Thorne-Roberts variable flavor scheme with MRST 99 (TR-VFS).<sup>7,8</sup>

## Conclusions and Prospects

Preliminary physics results of the NuTeV differential cross section results have been presented and structure functions have been extracted. The results are found to be in good agreement

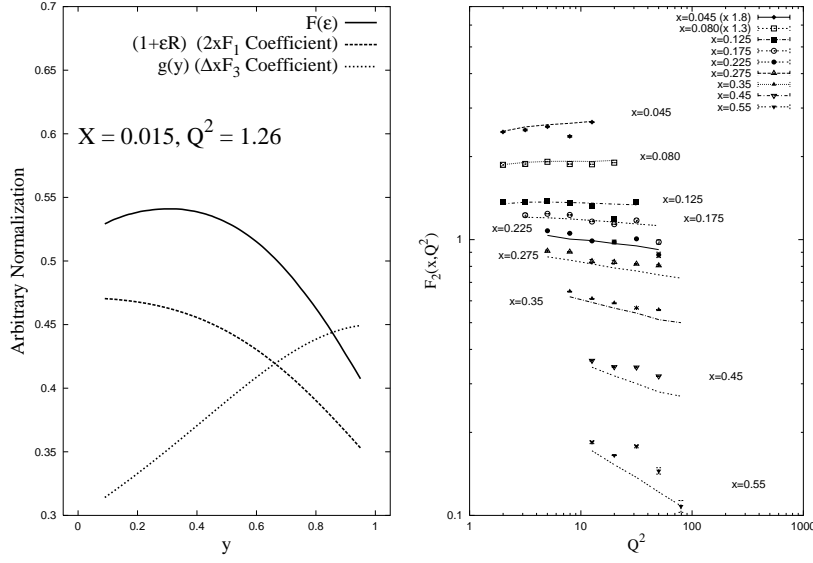


Figure 3: Left: An example fit. The upper curve is  $F(\epsilon)$  as a function of  $y$ . The  $y$ -intercept effectively gives the value of  $F_2$ , which is largely independent of the choice of  $R(x, Q^2)$ . Right: The extracted values of  $F_2$  from NuTeV and a curve showing the theoretical extraction of  $F_2$  as a function of  $Q^2$  with statistical errors.

with CCFR results.

The measurement of  $\Delta x F_3$  was performed using a model for  $R(x, Q^2)$ . Due to the positive correlation between  $R$  and  $\Delta x F_3$ , this measurement depends strongly on the input value for  $R$ . The results of this measurement have been found to be in excess of variable and fixed flavor model schemes, when an extrapolation of the world's knowledge of  $R$  is used to extract  $\Delta x F_3$ .

The prospects for improving upon the current preliminary measurement and the CCFR measurement rely on the improved calibration for NuTeV and the extended kinematic range. The extension of the kinematic range from NuTeV may provide great insight into the extraction process (see Fig. 3). The high- $y$  and low- $y$  data points are the most sensitive to the underlying structure function quantities. The calibration at lower hadronic energies extends the low- $y$  reach to lower  $Q^2$  for moderate  $x$ . The sign-selected beam allows the inclusion of high- $y$  events. This is where the sensitivity to  $R(x, Q^2)$  and  $\Delta x F_3$  is the greatest.

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